# III.E.2 Advanced Net-Shape Insulation for Solid Oxide Fuel Cells

## Objectives

- Develop a new product line of low-cost, alumina-based, silica-free, net-shape insulation materials for SOFC systems.
- Optimize materials processing to achieve low thermal conductivity in CERamic CAstable NAnoMaterial (CERCANAM) materials.
- Demonstrate long-term stability (>2,000 hours) of gallate SOFC button cells with selected CERCANAM compositions in the fuel and air sides.

## Accomplishments

- CERCANAM was successfully tested for over 5,000 hours in a gallate SOFC button cell test apparatus.
- Developed a scaled-up process to increase the slip batch size from 200 gm (in Phase I and early Phase II) to 5 kg.
- Demonstrated examples of making thick and thin sections of net-shape insulation using CERCANAM (scaled up the thickness of cast specimens from <1/8" [<12.5 mm] to 2" [50 mm]).
- Developed several complementary production-friendly processes to successfully fabricate insulation parts: (i) dry powder pressing, (ii) tape casting, and (iii) slip casting process.
- Presented a business plan at the DOE Commercialization Assistance Program (CAP) Forum based on CERACANAM technology for SOFC insulation and high temperature applications.


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## Introduction

The goal of this project is to develop a low-cost insulation material for SOFCs. Most commercially available insulation materials contain silica (5-100%). The presence of silica in the SOFC insulation is detrimental to the performance of the SOFC. Further, most insulations are available in the form of sheets, blocks, or panels which then have to be machined to get the desired fit around the fuel cell stack. Often, the machining cost can be a significant portion of the overall SOFC insulation installation cost. Thus, manufacturing techniques that produce appropriately shaped silica-free insulation parts without extensive machining and post-processing are very attractive for SOFC insulation.

## Approach

A new castable alumina (silica-free) insulation has been developed that utilizes the benefits of having fine porosity and high total porosity (low density) in order to obtain low thermal conductivity. The proposed technology is based on reaction bonding between alumina and a phosphate containing compound. This idea has led to the development of a new family of materials called CERCANAM. The reaction bonding approach eliminates the need for high temperature sintering and allows one to obtain net-shape components by casting or pressing the slip into the desired mold, followed by a low temperature (~900°C) firing.

## Results

Two different versions of CERCANAM-based insulation material have been developed for different applications within the SOFC system. These versions are called low density (<1.0 g/cc) and high density (>1.5 g/cc), respectively. The low density insulation would be the primary insulative (front face) component for the active fuel cell. The high density version will be suitable for applications where high temperature, structural load-bearing capability is required (like rails, guide posts, or bottom support panels). The properties of these two types of insulation are listed in Table 1 below.

An array of ceramic processes has been developed to enable low-cost manufacturing of this insulation: (i) dry powder pressing (isostatic or uniaxial - for making complex shapes like tubes, etc.); (ii) tape casting (for thin, wrap-around insulation sheets); and (iii) slip casting (for making thick panels or complex parts).

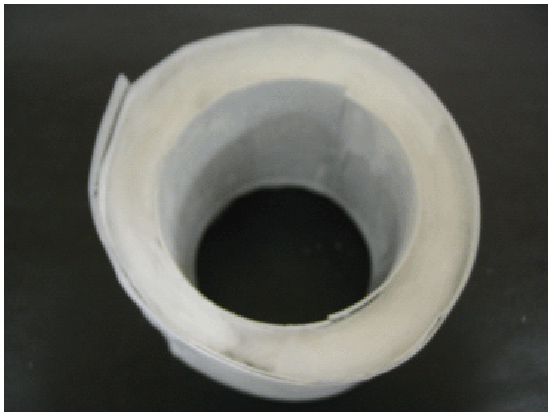
**TABLE 1.** Properties of CERCANAM-based SOFC Insulation

| | Low Density CERCANAM* | High Density CERCANAM* |
|---|---|---|
| Density Range (g/cc) | 0.6 – 1.0 g/cc | 1. 5 – 3.0 g/cc |
| 4-pt Flexural Strength (MPa) | < 1 MPa | 10 – 70 MPa |
| Thermal Conductivity at 800°C (W/mK) | 0.2-1.0 W/mK | 1-5 W/mK |
| Thermo-Chemical Stability | Stable at high temperature in air, $CO$, $CO_2$, $H_2$, $H_2O$, JP-8, Diesel vapor, Methanol vapor - No wt. loss | Stable at high temperature in air, $CO$, $CO_2$, $H_2$, $H_2O$, JP-8, Diesel vapor, Methanol vapor - No wt. loss |
| Coefficient of Thermal Expansion | ~8 ppm | ~8 ppm |

* Depending on the end requirements, the starting raw ingredients and slip composition can be appropriately chosen to achieve a specific density, flexural strength, and thermal conductivity value. Hence, a range of values is provided instead of absolute values. For example, a 0.7 g/cc low density CERCANAM may have a flexural strength of <1 MPa and thermal conductivity of 0.2 W/mK. For the high density CERCANAM (after 900°C firing), a wide range of density-flexural strength combinations can be designed into the material: 1.7 g/cc – 10 MPa; 2.0 MPa – 20 MPa; 2.4 g/cc – 40 MPa; and 2.7 g/cc – 70 MPa. When compared to commercially available insulation for structural applications, these are the highest reported strengths (for comparative density values) seen in product literature, as published by competitive insulation providers. The pore sizes range from nano to sub-micron to micron (<100 $\mu$m) sizes.

Figures 1 and 2 give examples of various products made using these different manufacturing techniques. In Figure 1, CERCANAM tape was used to encapsulate Saffil fiber-based mat insulation (95-97% alumina, 3-5% silica). Saffil mat insulation has a density of 0.35 g/cc and a thermal conductivity of 0.18-0.28 W/mK between 600°C – 800°C. The inner and outer CERCANAM lining (100 mil thick) provides added mechanical, thermal, and chemical protection to the Saffil insulation. The Saffil fiber-based insulation, by itself, does not have any structural integrity. However, the final fired composite structure shown in Figure 1 is easy to handle, is workable, and can take very small loads. In this way, the Saffil insulation can be fully enclosed within CERCANAM layers (including the top and bottom areas – not shown in Figure 1). Since the cost of Saffil mat and blanket insulation is $100 and $280 per cu. ft., respectively, this could be a very cost effective alternative approach for insulating SOFC systems. In Figure 2, an example of a 1.5" thick CERCANAM insulation is shown along with a second example of a net-shaped (rectangular picture frame) insulation made via a casting route. In the past, casting >1/8" thick samples had been a significant challenge which has now been overcome by using a proprietary mixing process that allows for making high solids loading slips.

To test the CERCANAM insulation for its affect on SOFC performance over a long-term period, CERCANAM samples were introduced into the air and



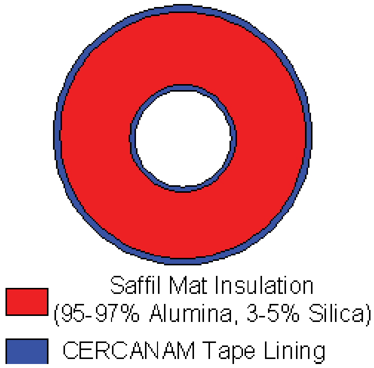



**FIGURE 1.** CERCANAM Tape Used to Encapsulate Saffil Fiber-Based Insulation for Added Mechanical and Thermal Protection

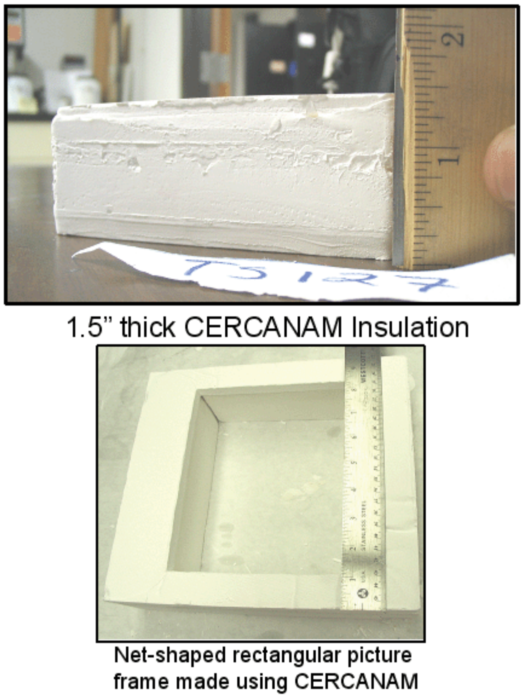



**FIGURE 2.** Examples of Thick, Net-Shape Insulation Samples Made Using CERCANAM

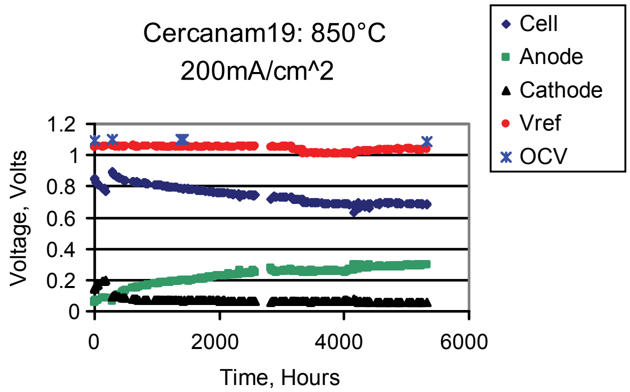



**FIGURE 3.** Gallate button cell performance test (up to 5300 hours) with CERCANAM samples on cathode and anode sides (CERCANAM samples were inserted into the anode and cathode sides at the 380th and 668th hour, respectively).

fuel ($H_2$) streams on the cathode and anode sides of the gallate button cell, and the fuel cell performance was monitored for over 5000 hours at 850°C. No cell degradation was seen, suggesting excellent thermo-chemical stability of this material (Figure 3).

A complete business plan for CERCANAM-based insulation was developed under the DOE project with feedback from Dawnbreaker Inc. This helped us to understand what kinds of issues (technology or business oriented) we need to solve, what kinds of risks we should expect, and what kinds of strategies we ought to develop in order to commercialize CERCANAM materials. The business plan was presented at the DOE CAP Forum in Falls Church, Virginia, in October 2005.

Future work will involve (i) developing a detailed cost analysis for producing products in a (future) manufacturing-type set-up and (ii) completing a SOFC system cost-benefit analysis to understand the complete system impact (material and installation cost) and compare the results with conventional approaches currently used for SOFC insulation.

## Conclusions

- Successfully demonstrated long-term compatibility of CERCANAM insulation in SOFC systems.
- Developed several complementary fabrication processes for low-cost manufacturing.
- Scaled up the sample thickness of cast specimens from 1/8” to 2” (16x improvement).
- Developed and presented a business plan at the DOE CAP Forum.

## Special Recognitions & Awards/Patents Issued

**1.** A provisional patent was filed in Oct 2005 on this technology. A full utility patent is due to be filed in July 2006.

## FY 2006 Publications/Presentations

**1.** A. Akash, B. Nair, M. Wilson, Q. Zhao, and J. Persson, “Net-Shaped Nanoceramics,” Amer. Ceram. Soc. Bull., Vol. 84 [6], 16-18, 2005.

**2.** A. Akash, B. Nair, J. Hartvigsen, M. Wilson, Q. Zhao, and J. Persson, “Ceramics Shape up for Fuel Cell Systems,” The Fuel Cell Review, p. 33, Oct/Nov 2005.

**3.** Business Plan Presentation at the DOE CAP Forum, Oct 24-25, 2005.